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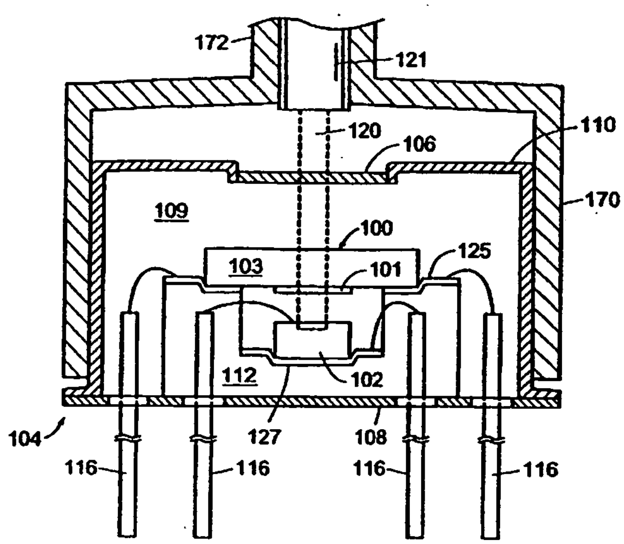


(57) Abstract: An optoelectronic device including a header (108) having an upper surface and including a plurality of pins (116) extending up through the upper surface; an optical device (102); a tunable optical filter (100), wherein the op and the tunable optical filter are arranged in a vertical stack mounted on and extending above the upper surface of the wherein the tunable optical filter is electrically connected to the plurality of conducting pins; and a cap (110) affixed to and along with the header defining a sealed interior containing the optical device and the tunable optical filter, wherein a top surface with a window (106) formed therein, and wherein the window is aligned with the tunable optical filter and device. Applications include a three-port add-drop multiplexer.

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# PACKAGE FOR ELECTRO-OPTICAL COMPONENTS

Under 35 U.S.C. §119(e)(1), this applications claims benefit of prior U.S. Provisional Application No. 60/335,178, entitled "Package for Tunable Filter Combi with Other Active Components," filed November 28, 2001, and U.S. Provisional Application No. 60/394,500, entitled "Low Cost Hermetically Sealed Multi-Port Pac for Optical and Opto-Electronic Devices," filed July 9, 2002.

## TECHNICAL FIELD

The invention relates generally to packages for optical components, includin thermo-optically tunable thin-film filters as well as other active and passive optical devices.

## BACKGROUND

Recently, a new device family has come into being, namely, thermo-opticall tunable, thin-film filters. These devices, which are made from amorphous semicond materials, exploit what had previously been viewed as an undesirable property of amorphous silicon, namely, its large thermo-optic coefficient. The performance of th devices is based on trying to maximize thermo-optic tunability in thin-film interferen structures, instead of trying to minimize it as is often the objective for conventional f filters.

Fig. 1 shows the basic device structure for the thermo-optically tunable thin f filter. The particular structure illustrated is a single cavity Fabry-Perot type filter 10. includes a heater film 12 integrated into the optical interference design, and a Fabry-l cavity made of a pair of thin film mirrors 14(a) and 14(b) separated by a spacer cavit In this example, heater film 12 is made of ZnO or polysilicon, so it is both electricall conductive and optically transparent at 1500 nm. Thin film mirrors 14(a) and 14(b) a alternating quarter wave pairs of high and low index films. The two materials are a-S (n=3.67) and non-stoichiometric SiNx (n=1.77). Because of the large index contrast between a-Si and SiNx, a relatively small number of mirror pairs is required. Even 4 pairs yields reflectivity R=98.5% at the design wavelength, and 5 pairs yields R=99.6

Cavity 16 is an integral number of half-waves, typically two to four, of amorphous silicon.

The amorphous thin films can be deposited by various physical vapor deposit techniques such as sputtering, or chemical vapor deposition techniques including pla: enhanced chemical vapor deposition (PECVD). PECVD is a particularly flexible an homogeneous thin film process, and control of the basic deposition parameters such plasma power, total gas pressure, hydrogen partial pressure, gas ratios, flow rates, an substrate temperature can be used to significantly modify film density and stoichiom which in turn influence index, optical absorptivity, and thermo-optic coefficients. In addition, hydrogenation of the a-Si films can be used to quench dangling bonds and thereby decrease defect densities which, in turn, reduces infrared absorptivity. As a plasma based technique, PECVD offers the process variability needed to more easily produce dense, compliant films of several optically distinct but process-compatible materials, such as amorphous silicon and amorphous silicon nitride, with widely diff indices. Transitions between materials can be accomplished by controlling gas mixtu without breaking vacuum.

The finesse that is achievable with the thermo-optically tunable, thin film filt illustrated by Fig. 2. In this case, the filter was a single cavity configuration using 6 mirror cycles and a fourth order spacer (4 half waves). The -3dB width was 0.085 nn a free spectral range of 388 nm and a finesse of approximately F=4,500.

The thermal tuning that is achievable is illustrated by Fig. 3. The configurati used an amorphous silicon spacer with dielectric mirrors (tantalum pentoxide high in and silicon dioxide low index layers, deposited by ion-assisted sputtering, R=98.5% mirror reflectivity). That structure was heated in an oven from 25C to 229C. The tur was approximately 15 nm or $d\lambda/dT$=0.08 nm/K.

Finally, the benefit of constructing a tunable filter with all-PECVD films usin amorphous silicon not only for the spacer but also for the mirror high index layers is illustrated in Fig. 4. This filter, with 4 period mirrors, incorporated an electrically conductive ZnO layer for heating internal to the film stack, which is able to achieve n higher local film temperatures than if it the heater was separate from the film stack. tuning range in this example was 37 nm.

Further details about these new structures can be found in U.S. Patent Applic: No. 10/174,503 filed June 17, 2002, entitled "Index Tunable Thin Film Interference Coatings;" and U.S. Patent Application No. 10/211,970 filed August 2, 2002, entitle( "Tunable Optical Instruments," both of which are incorporated herein by reference.

## SUMMARY

In general, in one aspect the invention features an optoelectronic device inclu a header having an upper surface and including a plurality of conducting pins extend up through the upper surface; an optical device; a tunable optical filter; and a cap affi to the header and along with the header defining a sealed interior containing the optic device and the tunable optical filter. The optical device and the tunable optical filter arranged in a vertical stack mounted on and extending above the upper surface of the header; the tunable optical filter is electrically connected to the conducting pins; and cap has a top surface with a window formed therein and aligned with the vertically stacked tunable optical filter and optical device.

In general, in another aspect, the invention features an optoelectronic device including a header having an upper surface and including a plurality of conducting pi extending up through the upper surface; an optical device supported on the top surfac the header with a major surface thereof substantially parallel to the upper surface of t header; and a cap affixed to the header and along with the header defining a sealed interior containing the optical device. The cap has a top surface with a first window formed therein and the header has a second window formed therein.

Different embodiments include one or more of the following features. The he and cap are a Transistor Outline (TO) package. The tunable optical filter is a thermo optically tunable thin-film filter. The optical device is an emitter (LED) or a detector The optoelectronic device also includes a standoff structure mounted on the top surfa the header and defining a first surface on which the optical device is mounted and a second surface on which the tunable optical filter is mounted. The cap on the header forms a hermetically sealed interior and may include a collar holding a fiber collimat other fiber optics. The optoelectronic device also includes a substrate with the filter formed on one surface thereof and the optical device mounted on an opposite surface thereof.

Various embodiments of the invention have one or more of the following advantages. They provide a low-cost, small-footprint package. They provide for "fre space" tunable filters that do not rely on waveguide effects, but rather treat collimate beams in free space to achieve wavelength filtering. Packaging can use established, standard enclosures (e.g. TO packages) that have been modified appropriately. In th event, the packaging approach can take advantage of well-established assembly techniques and widely available, inexpensive enclosures. This will result in drastical reducing the cost of assembly and materials, as compared to using custom packaging designs. In addition, it lends itself to easily producing sealed packages (optionally, hermetically sealed) that have electrical feed-throughs and one or more transparent windows through which light travels. Moreover, eliminating the need for optical fib feed-throughs also dramatically reduces the cost of packaging and enhances the relial of the overall system.

Hermetic packages of the types disclosed herein are desirable for optical components due to the strict reliability requirements of optical communications syste Current hermetic multi-port optical device packaging technologies include butterfly, mini-DIL, and innumerable machined aluminum packages of custom design. To mai hermeticity, most packages used for pass through optics employ laser welding for sea sealing, which is both complex and expensive to implement in production. The simp packages of this type often cost upwards of $20.00 each, while the more complex can approach hundreds of dollars.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and 1 the claims.

## DESCRIPTION OF DRAWINGS

Fig. 1 shows the basic device structure of a thermo-optically tunable thin film filter.

Fig. 2 is a plot of filter transmission characteristics showing the finesses of a single cavity, thermo-optically tunable, thin-film filter.

Fig. 3 presents multiple plots of filter transmission characteristics showing th tuning range of a filter with thermo-optic spacer and dielectric mirrors.

Fig. 4 presents multiple plots of filter transmission characteristics showing th tuning range of an all-PECVD filter, including a-Si:H high index layers and spacer, S low index layers, and 4 period mirrors.

Fig. 5A is a cross-sectional cutaway view showing the core elements of one f of embodiments.

Fig. 5B illustrates an alternative design for the cap on the package.

Fig. 6 show a modified TO package embodiment.

Figs. 7A, 7B and 7C show modified TO packages with different types of win in the top of the can.

Fig. 7D shows a dual-inline package embodiment.

Figs. 8A and 8B shows a multi-port embodiment with axially aligned input a output ports at the top and bottom, respectively.

Figs. 9A and 9B show a three-port device which is an optical add/drop multiplexer.

Figs. 10A-D show four general categories of optical component configuratio

Fig. 11 shows an exploded view of an approach to aligning the fiber/collimat onto the package containing the opto-electronic components.

Figs 12A and 12B illustrate the alignment procedure for optimizing return lo

Figs. 13A-C illustrate alternative assembly techniques that can be used.

Figs. 14A and B illustrate techniques for making multiple die on a single substrate.

Fig. 15 shows another multi-port embodiment.

Like reference symbols in the various drawings indicate like elements.

## DETAILED DESCRIPTION

Referring to Fig. 5A, one family of embodiments involves packaging a free-s tunable optical filter component 100 together with one or more passive and/or active optical/optoelectronic components 102 in a "stack up" format inside a package 104 v

an optical access window 106 through which a free-space optical beam can pass. Package 104 includes a header 108 with a cap 110 mounted thereon and forming a se interior cavity. A stand-off element 112 is affixed to header 108 and a plurality of electrical pins 116 come up through header 108 to enable electrical connections to be made to tunable filter component 100 and to other optoelectrical components inside package 104. Stand-off element 112 holds tunable filter component 100 and optoelectronics 102 in a vertically arranged stack with the major plane of filter component 100 arranged substantially parallel to the upper mounting surface of head 108. In operation, a light beam 120 from a optical fiber 121 passes through window into the interior of package 104 where it then passes through tunable filter componen 100. A filtered beam exiting the other side of tunable filter component 100 then imp on optoelectronics 102.

Stand-off element 112 is made out of an electrically insulating material such ceramic (e.g. alumina or aluminum nitride). This element suspends tunable filter 10( fixed, well-controlled distance above optoelectronics 102 (e.g. a PIN detector or LEI emitter). Additionally, conductive traces (or contact pads) 125 and 127 may be defir on this stand-off for the purpose of contacting and interconnect. In the described embodiment, filter component 100 includes a substrate 103 with a tunable thin-film f element 101 formed in its downward facing surface. This is an example of flip-chip mounting according to which the device is flipped over and mounted onto the stand- facilitate making electrical connections to the metal traces formed on the substrate surfaces.

Using passive alignment guides or reference marks, the tunable filter and the optoelectronic components may be accurately aligned in the x-y plane where typical requirements for free-space elements is on the order of 10 microns, and may be accu placed along the z-axis. Such assembly, which may be accomplished using standard chip-mounting equipment - and possibly done in large volumes on an automated line dramatically more cost-effective than "silicon micro-bench" type assemblies typicall used for multi-element optical communications assemblies. In addition, it is signific more resilient mechanically because all components lay flat on stand-off or package surfaces rather than be arrayed as vertically oriented elements over a horizontal surfa

Again referring to Fig. 5A, a cover 170 with an integrally formed collar 172 located in its top fits onto cap 110 of package 104. Cover 170 holds optical fiber 12 (which may include collimating or focusing optics at its end) within collar 172 and properly aligns it with respect to window 101 within package 104. The collimating can take various forms including a GRIN (gradient index lens) or a ball lens. Simila the focusing optics can also take various forms.

Alternatively, as shown in Fig. 5B, a modified cap 110' can be provided whi includes a collar 119 integrally formed therein. Optical fiber 121 is sealed in collar 1 and serves as the window into the package. This does away with the need of providi separate cover as shown in Fig. 5A.

Referring to Fig. 6, an example of a commonly available package that can be is a TO ("Transistor Outline") style package which includes a round metallic can 21( Fig. 7A) mounted on a header 208. Header 208 has multiple integral conducting pin ("feet") 216 extending through it and hermetically sealed within the pass-throughs us solder glass. These conducting pins provide a way to electrically address or connect the internal optoelectronics and associated elements. When fully assembled, the pin connected to corresponding metallic pads on the enclosed optoelectronics by wires.

The optoelectronic components shown in the embodiment of Fig. 6 are the sa as those that are shown in Fig. 5. In addition, mounted on header 208 is a temperatu sensor (e.g. thermistor) that is used to monitor the temperature of the package to aid i operation of the thermo-optically tunable thin film filter.

Referring to Figs. 7A-C, the TO package lends itself particularly well to optic devices that require incident light perpendicular to the device plane, such as Fabry-P filters. Can 210 is modified by including in its top surface a window which may be of several different designs. For example, it could be a ball lens 206(a) (see Fig. 7A) could be a flat window 206(b) of the type that is used for single detectors (see, Fig. 7 or it could be an integrated lens 206(c) (see Fig. 7C). The cost of materials in such a package is less than one dollar, which is dramatically lower than "butterfly"-type packages with fiber feedthroughs that are widely used in the industry. In addition, manual or automated equipment for assembling, wirebonding, and sealing such a pac is readily available and comparatively low-cost.

Referring to Fig. 7D, an example of another commonly available package tha be used is a dual-inline package 300 with a top window 306 of the type used for line: detector arrays. The dual-inline package also includes a header that defines a planar surface onto which the optoelectronic elements are stacked vertically, as described al Pins 316 extend out of the bottom side of the header and provide a means by which c can electronically connect to the optoelectronic devices within the sealed package. Window 306 provides a transparent region in the top of the package through which a optical beam can reach the enclosed optoelectronic devices.

Multi-Port Package

Figs. 8A and 8B show a further modification of the design described above. generic configuration for a 2-port, TO package and includes an integrated feed-throu which allows optical signals to pass through optoelectronic circuitry inside of the package.

In this example, the modified TO package, like the one previously described, includes a metal cap 510 sealed onto a header 508. Within header 508 there is a plur of conducting pins 516 extending up through the header. In the top of cap 510, there window 506 with its perimeter sealed to the metal of the cap. An integrally formed, ferrule 530 extends upward from the main body of cap 510 and surrounds window 5( Ferrule 530 holds an optical fiber 540 enclosed in a sleeve 542. A ball lens 544 is attached to the end of optical fiber 540 and adjacent to window 506. Ball lens 544 collimates the light coming out of the optical fiber before it passes into the modified package. Header 508 includes a thru-hole 546 formed at its center with a window 52 the top end of this thru-hole and sealed in a recess formed in the upper surface of hea 508. A ferrule 531 extends down away from the bottom of header 508 and aligned w thru-hole 546. Ferrule 531 holds another optical fiber 535 enclosed in a sleeve 541. ball lens 543 is affixed to the top of optical fiber adjacent to window 529.

This arrangement defines an optical path through the center of the package al its longitudinal axis. Any one of a number of different combinations of optoelectroni devices 550 can be mounted on the header inside the package and in the optical path.

An example of a three-port configuration is shown in Fig. 9, is an optical add/ multiplexer 600. It includes a thermo-optically tunable thin-film filter 601 mounted ( header 608 and inclined at a slight angle (e.g. < 5°) relative to the upper surface of th header. A dual fiber collimator 620 (e.g. a GRIN lens) is positioned within a ferrule extending out of the top of cap 610 with two optical fibers 612 and 614 connected to end of the dual fiber collimator. Optical fiber 612 represents an input channel and op fiber 614 represents an output channel. At the other end of the package is a third opti fiber 619, aligned with a thru-hole similar to what was described in connection with t device shown in Fig. 8A. Thermo-optically tunable thin-film filter 601 and dual-fibe collimator 620 are aligned relative to each other so that an incoming light beam 603 f optical fiber 612 impinges on tunable optical filter 601 at an angle that is slightly less perpendicular its surface.

Incoming beam 603 represents a number of different channels, each at a diffe wavelength. A characteristic of tunable thin-film filter 601 is that it passes a selectab one of the wavelengths on to fiber 619. The remainder of the channels (i.e., wavelen that are outside of that narrow transmitted passband are reflected off tunable thin-film filter 601 and back towards dual fiber collimator 620 as a reflected beam 605. The relative alignment of tunable thin-film filter 601 and collimator 620 is such that the reflected wavelengths enter collimator 620 and are directed into output fiber 614. A transmitted beam 607 passes out into optical fiber 619. In this mode of operation, the device acts as a drop multiplexer, i.e., it drops or pulls off a selected one of the multi channels of the input optical signal.

Alternatively, if the optical signal of the appropriate wavelength is input throu fiber 621, the device functions as an optical add multiplexer, i.e., it adds the new chai to the multi-channel signal that is passing through the device.

Referring to Fig. 15, another multi-port configuration utilizes multi-port input multi-port output optics as well as add/drop optics to allow a more efficient package design. This performs the functions of two or more three-port packages in a single si plus port design. This is desirable due both to space and power consumption considerations. Both add and drop processes occur in this single assembly, permitted the use of differing angles of incidence for the add cycle and the drop cycle, yet still

utilizing the same position on the filter surface. This avoids interference effects whic would otherwise result in degradation of both the transmitted and reflected signals. Add/drop, add/add, or drop/drop configurations may be attained in this package configuration, dependent only on input/output arrangement.

The disclosed embodiment includes two GRIN lenses 1000 and 1002 (or othe comparable optical elements). There are four optical fibers connected to lens 1000, symmetrically arrayed across the input face of the lens. As is well known, light bean that are displaced from the central axis of the lens come out of the other end of the le: an angle determined by the displacement of the optical fiber from the central axis. Tl principle is used to advantage in the following way.

Connected to lens 1000 are four optical fibers 1010, 1011, 1012, and 1013 lin arranged in symmetrical fashion about the central axis of the lens. In other words, op fibers 1010 and 1013 are the two outer fibers each equally distant from the axis of ler 1000 and optical fibers 1011 and 1012 are the two inner fibers also equally distant frc the central axis of the lens. Optical fiber 1010 supplies a multi-channel optical input signal to lens 1000, which in turn delivers that signal to a tunable filter 1004 at an an relative to its normal direction. Tunable filter 1004 passes a selectable one of the channels of the input signal through to lens 1002, which supplies it to a drop fiber 10 placed at the appropriate location on the face of lens 1002. The rest of input signal reflects off of tunable filter 1004, back through lens 1000, and into optical fiber 1013 Optical fiber 1013 is connected to optical fiber 1011 so as to deliver its received sign: bask to lens 1000 at the location of optical fiber 1011. This returned optical signal is back to tunable filter 1004 but this time at a smaller angle relative to its normal. Whe reaches tunable filter, since the selected channel has already been removed, all of it is reflected back to lens 1000, which delivers that reflected signal to output optical fiber 1012.

Input fiber 1014, which carries an ADD signal at the frequency of the droppe channel, supplies an optical signal to the backside of tunable filter 1004 and at an ang such that when it is transmitted by filter 1004 it combines with the reflected signal th: delivered to output fiber 1012.

Other Implementations

Various applications require different combinations of tunable filters, optics, other active devices in small packages. Figs. 10A-D show four general categories of possible combinations of tunable filters with other active optoelectronics, though this of examples is not exhaustive.

The combination illustrated in Fig. 10A includes input optics, a tunable filter and a detector 704. Input optics 700, which my include a collimator, delivers an opti signal that is made up of multiple wavelengths to tunable filter 702, which allows a selectable one of the multiple wavelengths of the optical signal to pass through to det 704. Typical applications for this system include spectral power monitoring and sing channel detection or monitoring. In the case of spectral power monitoring, tunable fi 704 is operated to scan back and forth over the wavelength range of interest and dete 704 measures the powers of the different wavelengths within the optical signal. In th case of single-channel detection or monitoring, tunable filter 702 is tuned to a single wavelength and detector 704 monitors the signal in that band - a "tunable detector" o "tunable receiver"). In any event, the system is typically not designed to return reject wavelengths to output optics.

The combination illustrated in Fig. 10B, includes input optics 710, a tunable f 712, a detector 714, and output optics 716. A typical application of such a system is "optical drop" according to which tunable filter 712 admits a single channel to detect 714, and the wavelengths rejected by tunable filter 712 reflect into output optics 716, as a collimator. Such a configuration would be useful in a flexible communications network in which each location can dynamically select which communications chann (i.e., wavelength) to detect.

The combination illustrated in Fig. 10C includes a broadband light source or emitter 720, a tunable filter 722, and output optics 726. Broadband light source 720, as a light-emitting diode (LED), is used in conjunction with tunable filter 722 to crea tunable narrowband light source. When tunable filter 722 is a thermo-optically tunab thin film filter, such as was described above, it becomes possible to create a low-cost tunable source for measurement applications or low-cost optical networks.

The combination illustrated in Fig. 10D includes input optics 730, a tunable f 732, an emitter 734, and output optics 736. Emitter 734 may be either a broadband, 1 emitter or a tunable, narrowband emitter, such as a tunable vertical cavity surface emitting laser which is "added" into an optical stream by way of a tunable filter. In ti instance, tunable filter 732 admits the new wavelength along the same path as the reflected ("through") wavelengths. Such a system could work in conjunction with th system shown in Fig. 10B to dynamically add and drop wavelengths in a network, or could be used as a "universal spare" transmitter that can be set to any wavelength nee

There may be a broad range of applications that require similar systems, whe active optical elements besides the tunable filter are detectors, emitters, or other optic elements used to measure or treat light. With the packaging ideas presented herein, i now becomes possible to construct such systems in a low-cost, small form factor ma to make their widespread application feasible.

Beam Alignment

Return loss is the ratio of the amplitude of the reflected wave to the amplitud the incident wave. In optical applications this is measured in –dB, and for a compon the reflected power is defined as the total reflection from all surfaces within a compo which are conducted back through the optical fiber. Virtually all optical systems pla restrictions on the amount of RL for reasons of stability.

Optical assemblies that are manufactured with a Return Loss (RL) specificati are routinely designed and toleranced both in components and assembly such that a calculated angle of incidence is achieved between the component surface(s) and the source(s). This angle is calculated to provide sufficiently High RL to meet customer specifications. However, since the performance of most optical components degrade a function of angle (due primarily to polarization dependence), there is a trade-off, between the amount of buffer needed to cover mechanical tolerance stack-ups and th required device performance. This level of precision in both device and tooling is prohibitively expensive and extraordinarily difficult to design, maintain and manufac

An alternative to this process of specifying tight tolerances on the component been to utilize costly and cumbersome tip/tilt action to achieve the desired alignment

this case, RL is actively monitored while automated equipment tips, tilts and rotates t components relative to the source until the performance requirements are satisfied an then the component is fixed in that position. This process, however, requires highly precise automated equipment that is very expensive.

A new alignment method which achieves the required RL parameters, which be implemented with off-the-shelf tooling, and which is much less expensive will no described with the aid of Fig. 11 and Figs. 12A and B. This new method is also an a alignment process according to which the orientation of the source is changed to opti a monitored RL. The method works on loosely toleranced parts such as those descril herein, though it is applicable to any axially aligned system.

Referring first to Fig. 11, a packaging structure which is designed to impleme the improved alignment procedure includes a modified TO package 800 with a cap 8 attached to a header 804. On header 804 there is mounted a tunable thin-film optical filter 806 (or an optical device to which the input fiber is to be aligned). In the descri embodiment, tunable filter 806 is mounted at a small angle (Φ) relative to the underl top surface of header 804 (or stated differently, so that its normal is at a small angle ( relative to the longitudinal axis 830 of the package). A sleeve assembly 810 which h an optical fiber 818 and a collimator 815 slides over and loosely fits onto cap 802 of package, thereby roughly aligning the fiber with the window in the top of the cap. U sleeve assembly 810 is anchored to the cap (e.g by means of an epoxy or screws in th side of the sleeve), sleeve assembly 810 is capable of being rotated on the cap about longitudinal axis 830 of the package. A cover 820 slides over and covers the sleeve ( the sleeve is properly oriented.

Sleeve assembly 810 holds the fiber and collimator at a small angle (Ω) relati its axis of rotation (which for the package illustrated is also the longitudinal axis of tl cap/package). As illustrate by Figs. 12A and B, by rotating sleeve assembly 810 abo axis of rotation while it is fitted onto cap 802, the angle between the optical beam an normal to the surface of the optical component sweeps through all angles Φ - Ω throu Φ + Ω. For example, if the collimator and the normal to the component are parallel t each other (i.e., Φ = Ω), but off angle from the axis of rotation by 2 degrees, then the

angle of incidence may be varied using this method from 0-4 degrees. This angular differential may be either designed or a byproduct of assembly/manufacture.

By actively monitoring the input to and output from the optical fiber during tl rotation operation, the desired high Return Loss can be achieved within tenths of a dl minimizing any degradation due to higher than necessary angle of incidence.

If the sleeve fits loosely on the cap, there can also be an XY alignment step di which the sleeve is moved in a plane parallel to the plane of the header to find its optimum location as a function of device performance. Similarly, since there is a "w to the beam coming from the collimator, where all rays are presumed to be near paral this is where the active optical component surface is ideally placed. But in view of tl low divergence of the beam, this is very loosely toleranced, that is, both filter performance and RL are typically quite insensitive to Z position. So alignment in thi dimension (i.e., the Z axis) can be satisfactorily achieved by using a simple mechani stop in the sleeve that sets the Z position of the collimator relative to the optical component.

A full alignment procedure involves the following sequence of steps while monitoring the measured RL. First there is a course adjustment in the Z-direction. T RL is optimized by rotating the sleeve. Next, further optimization of device perform is achieved by aligning in the XY plane. And finally, there is a further fine adjustme the Z direction.

<u>Stacking Buildup Methods</u>

As mentioned above, an advantage of some of the embodiments described he that they permit the use of Z-axis buildup methods of fabrication. The Z-axis buildu methods are low cost and include but are not limited to: (1) multilevel (e.g. stepped) stand-offs such as ceramics used to space apart components along the z-axis and alig them on the x-y plane; (2) flip-chip mounting of optical/optoelectronic and other chi onto passive substrates and/or substrates on which other optoelectronic elements are fabricated; (3) pre-mounting of components onto substrates/stand-offs and assembly a package using passive alignment of these substrates; and (4) mounting of substrates components directly onto electrical pins inside the package.

Assembly Guides Used

As illustrated in Figs. 13A-C, several patterning methods are available to minimize the assembly precision and effort required. For example, referring first to 1 13A, a mask or aperture 900 can be patterned on one component (e.g. tunable filter 9 and then the other component (e.g. a detector 904) can be designed to have a signific larger active area 906 to account for passive alignment tolerances. In addition, referr to Fig. 13B, one can use standardized surface-mount technology (SMT) assembly methods and machines to obtain high alignment accuracies, possibly with the aid of optical alignment guides that are interpreted by SMT machinery. In that case, for example, a detector or emitter chip 920 can be flip-chip mounted onto a back surface substrate 922 that has a tunable, thin-film optical filter 924 formed on its front surfac There can be photolithographically defined alignment guides 926 and contacts 928 formed on the back surface of substrate 922 to facilitate alignment and contact to det or emitter chip 920. Alternatively, one can use intermediate masks on substrates or o to align individual optical/optoelectronic components. Also, one can build hybrid structures as illustrated by Fig. 13C. For example, a substrate or board 940 holding c circuitry or connectors 950 (such as drive circuits or read circuits) can be provided w an optical thru-hole 942 to enable optical communication between components that a be mounted on both sides of substrate 940 (e.g. a tunable optical filter chip 944 that i flip-chip mounted on one side of substrate 940 and a detector or emitter chip 946 tha flip-chip mounted on the other side of substrate 940).

In addition, large-volume assembly of components based on conventional electronics methods (SMT, for instance) may be used to build optoelectronic assemb in "sheets" before separating and packaging them. An example of such an assembly process is shown in Figs. 14A and B, where a detector element 980 and a thermistor element 982 are mounted on the reverse side of a tunable thin film filter substrate 98 Several hundred or thousand such subassemblies may be automatically assembled an solder reflow (or wirebond) process applied before the thin film filter wafer is diced a the resulting subassemblies are packaged.

Fig. 14B illustrates one method of building such assemblies. Substrate 984 i: patterned to accept detector element 980, thermistor element 982, a tunable filter ele 988, and possibly other components, and is then diced. Certain pieces of the substra then stacked to create stand-off elements with patterned metal traces.

Optics Used

The optical configurations that may be used with the packages described abo include, but are not limited to: (1) inbound optical signals, outbound optical signals, both in-bound and outbound optical signals; (2) collimated or focused beams, thougl preferably collimated in the case of the tunable filter; (3) using only external optics c a combination of external and internal optics, or internal, package-integrated optics c (4) passive optical coatings used on external optics, on the transparent window to the package, or on internal elements such as substrates for the purpose of anti-reflection coatings, high-reflection coatings, or selective wavelength filtering; and (5) optical elements such as single- or dual-fiber collimators used external to the package, lense integrated into the package itself, or micro-optical elements used in the stack-up of components internal to the package.

Aperture Plate

In the embodiments that use a thermo-optically tunable thin-film filter, the he element in the tunable thin film filter should typically be made as small as possible f least two reasons. First, the speed of the device will be faster for a smaller heater be a smaller thermal mass needs to be heated and cooled. Second, the device can run at lower power because the temperature of the tunable element is proportional to the pc density. For a given required maximum temperature, and therefore a given required power density, the smaller the heater, the lower the required input power.

However, the drawback to having a small heating element is the difficulty cre in trying to optically align it to a free space, collimated beam. All of the light transm through the tunable filter must pass through the heated portion of the device. Any lig transmitted through an unheated part of the filter, or through an un-filtered part of the

device will contain unwanted wavelengths, and will add unwanted noise to the desir signal.

To realize very low cost packaging, alignment should be as easy, passive, and automated as possible. One approach to achieving this is by integrating into the devi layer that blocks any light from being transmitted through any part of the device exc the heated portion of the tunable filter. In its simplest form, this would be a metal la 907 with a small aperture aligned to the heating element, as shown in Fig. 13A. In tl case, the alignment only has to be good enough to ensure that some part of the collin beam hits the aperture. The rest of the collimated beam can hit outside the heater are with no consequence because this light will be reflected, not transmitted. Therefore, light-blocking layer with an aperture ("aperture layer") enables a relatively small hea Also, the aperture should be small compared to the heater area. This will ensure that temperature non-uniformities near the edges of the heating element are minimized, leading to a narrower peak.

The aperture layer should be thick enough to have enough reflectivity to rejec required amount of light. However, if it is too thick it can add unwanted stress to the stack and/or contribute detrimental thermal properties to the device by conducting av too much heat. If the aperture layer does conduct away too much heat, it can lead to non-uniform temperature distribution in the aperture, and will require more input po to the heater to reach a given temperature. Also, the aperture layer needs to be able t withstand the possibly high temperatures required to tune the device. Some commor metals that could be used for this purpose include: Al, Ag, Cu, Au, Pd, Pt, Ni. Fe, Cr, and Ti. Ideally, the material would have a high k value at the wavelength of interest 1550nm), a high melting temperature since metals will typically soften and creep at a fraction of their melting temperature, a low thermal conductivity, and a low thermal (i.e., mass density x specific heat) so the aperture layer does not conduct away too m heat. Note that non-metallic materials are also an option for the aperture layer.

Free-Space Filters:

The types of tunable filters which can be used in the embodiments described herein are "free-space" filters that admit beams of light that may be collimated and fi

out a specific wavelength or sets of wavelengths for transmission or reflection. Thes filters are referred to as "free-space" filters because the optical beams to be filtered a unguided except for input and output optics which extract them from and insert them waveguides such as optical fibers. A number of such tunable optical filter devices ar known in the art. These include, but are not limited to:

- Tunable, thin film optical filters, including the thermo-optically tunable thin filters mentioned above, which have great advantages in terms of performanc cost, and reliability and fit this packaging format exceptionally well.
- Microelectromechanical systems (MEMS)-based Fabry-Perot filters using tw more dielectric mirrors that are moved together or apart for tuning purposes; includes both conventional silicon-based MEMS and those devices based on polymer films or other materials.
- Holographic or grating waveguide-coupled filters where in-plane patterns are to create a filter for light traveling along the z-axis (or used to deflect a partic wavelength or set of wavelengths off-axis).
- Piezo-electric Fabry-Perot based on Piezo thin films.

Many other free-space filters that exist or are under development will benefit from th packaging approach described in this disclosure.

It is to be understood that while the invention has been described through the of detailed embodiments thereof, the foregoing description is intended to illustrate ar not limit the scope of the invention, which is defined by the scope of the following claims. Thus, other aspects, advantages, and modifications are within the scope of th following claims.

**WHAT IS CLAIMED IS:**

1. An optoelectronic device comprising:

a header having an upper surface and including a plurality of conducting pins extendin through the upper surface;

an optical device;

a tunable optical filter, wherein said optical device and said tunable optical filter are ar in a vertical stack mounted on and extending above the upper surface of the header and where tunable optical filter is electrically connected to a set of said plurality of conducting pins; and

a cap affixed to the header and along with the header defining a sealed interior contain optical device and the tunable optical filter, wherein said cap has a top surface with a window formed therein, said window aligned with the tunable optical filter and the optical device.

2. The optoelectronic device of claim 1 wherein the header and cap are a Transistor O (TO) package.

3. The optoelectronic device of claim 1 wherein the tunable optical filter is a thermo-optically, tunable thin-film filter.

4. The optoelectronic device of claim 1 wherein the optical device is an emitter (LED)

5. The optoelectronic device of claim 1 wherein the optical device is a detector.

6. The optoelectronic device of claim 1 further comprising a standoff structure mounte the top surface of the header, wherein the standoff structure defines a first surface on which th optical device is mounted and a second surface on which the tunable optical filter is mounted.

7. The optoelectronic device of claim 1 wherein the cap on the header forms a hermeti sealed interior.

8. The optoelectronic device of claim 1 wherein the cap includes a collar holding a fib coupling optics.

9. The optoelectronic device of claim 1 further comprising a substrate with the filter f on one surface thereof and the optical device mounted on an opposite surface thereof.

10. An optoelectronic device comprising:

a header having an upper surface and including a plurality of conducting pins extendir through the upper surface;

an optical device supported on the top surface of the header with a major surface there substantially parallel to the upper surface of the header, wherein said optical device is electric connected to a set of said plurality of conducting pins; and

a cap affixed to the header and along with the header defining a sealed interior contain optical device, wherein said cap has a top surface with a first window formed therein and the l has a second window formed therein.

11. The optoelectronic device of claim 10 wherein the header and cap are a Transistor Outline (TO) package.

12. The optoelectronic device of claim 10 wherein the tunable optical filter is a therm optically, tunable thin-film filter.

13. The optoelectronic device of claim 10 wherein the optical device is an emitter (LE

14. The optoelectronic device of claim 10 wherein the optical device is a detector.

15. The optoelectronic device of claim 10 further comprising a standoff structure mou on the top surface of the header, wherein the standoff structure defines a first surface on whicl optical device is mounted and a second surface on which the tunable optical filter is mounted.

16. The optoelectronic device of claim 10 wherein the cap on the header forms a hermetically sealed interior.

17. The optoelectronic device of claim 10 wherein the cap includes a collar holding a collimator wherein the window is a lens.

18. The optoelectronic device of claim 10 further comprising a substrate with the filte formed on one surface thereof and the optical device mounted on an opposite surface thereof.

19. The optoelectronic device of claim 10 wherein the cap includes a furrule extendin; upward from its top surface and providing a bore for holding an optical feed.

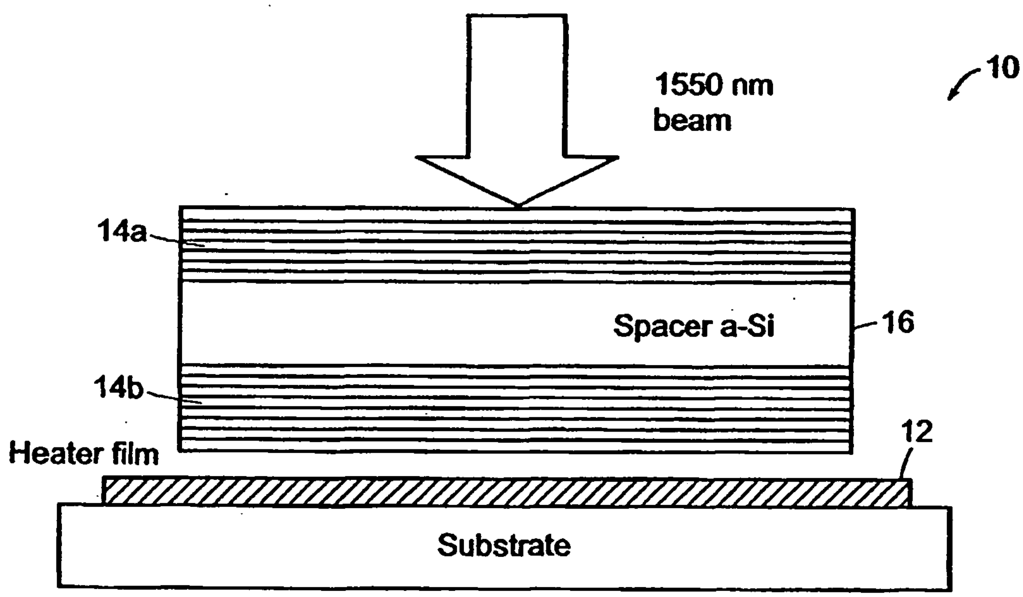

1550 nm
beam
10
14a
Spacer a-Si
16
14b
Heater film
12
Substrate

FIG. 1

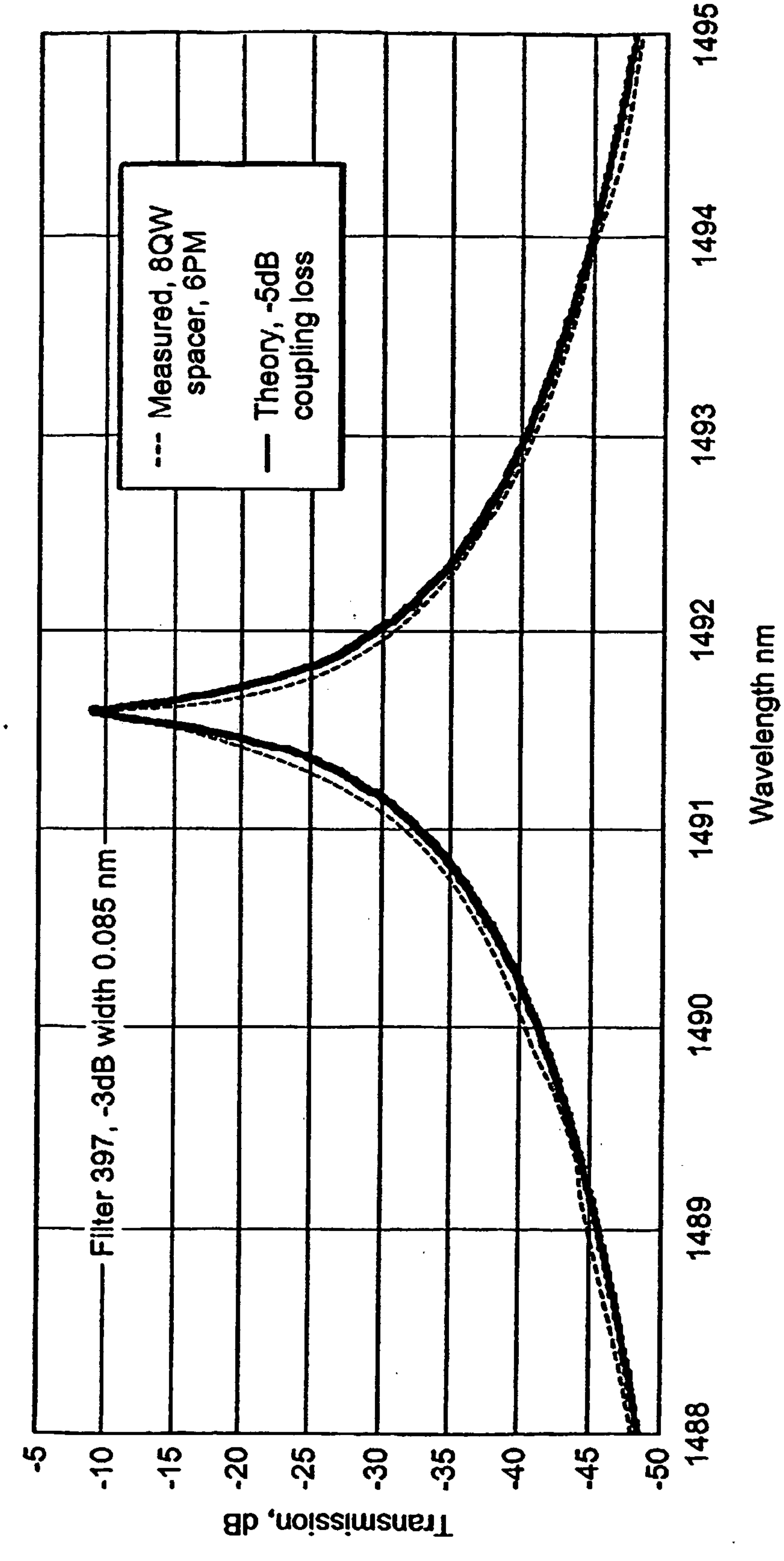

Filter 397, -3dB width 0.085 nm
--- Measured, 8QW spacer, 6PM
— Theory, -5dB coupling loss
Transmission, dB
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1488
1489
1490
1491
1492
1493
1494
1495
Wavelength nm

FIG. 2

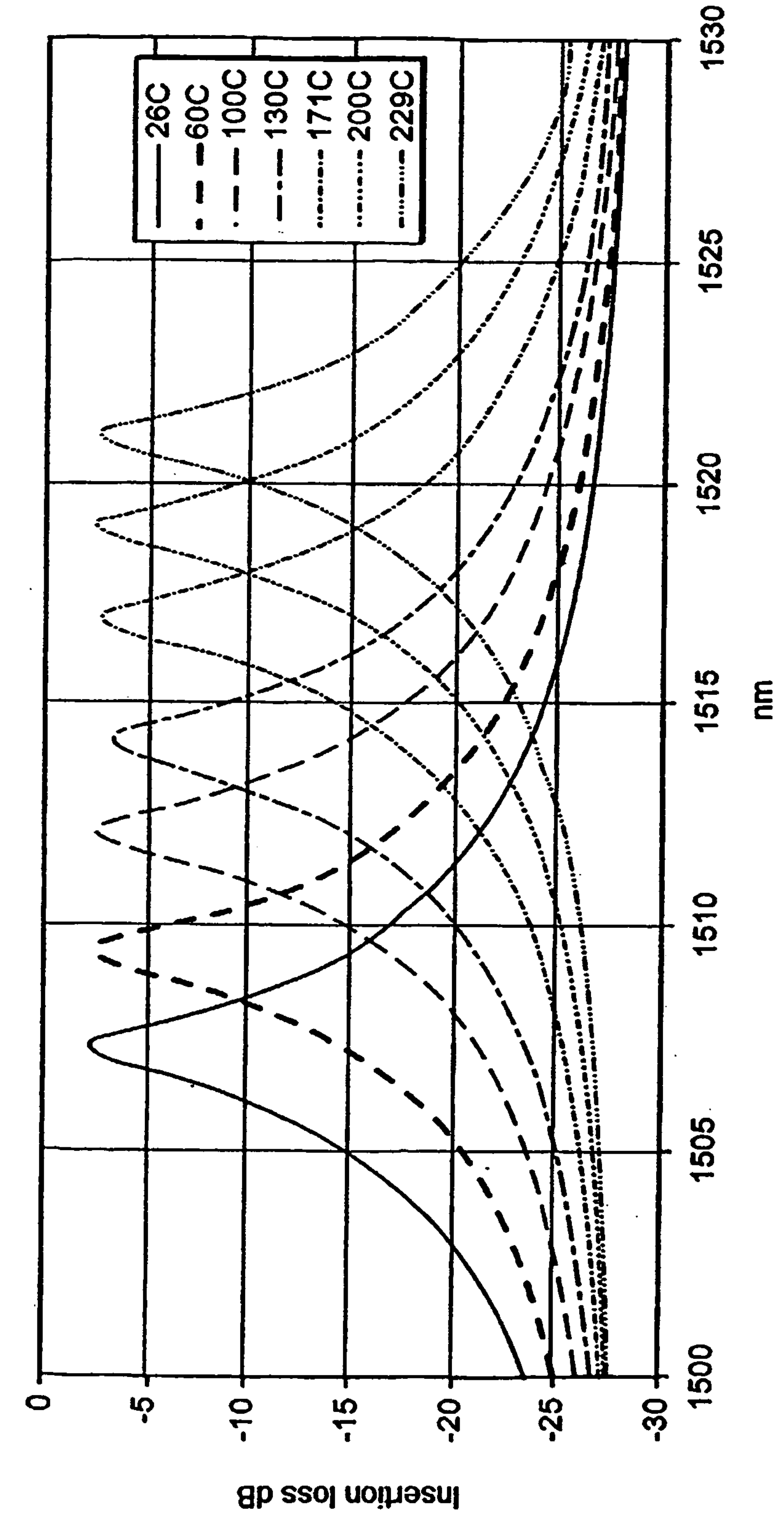

26C
60C
100C
130C
171C
200C
229C
0
-5
-10
-15
-20
-25
-30
Insertion loss dB
1500
1505
1510
1515
1520
1525
1530
nm

FIG. 3

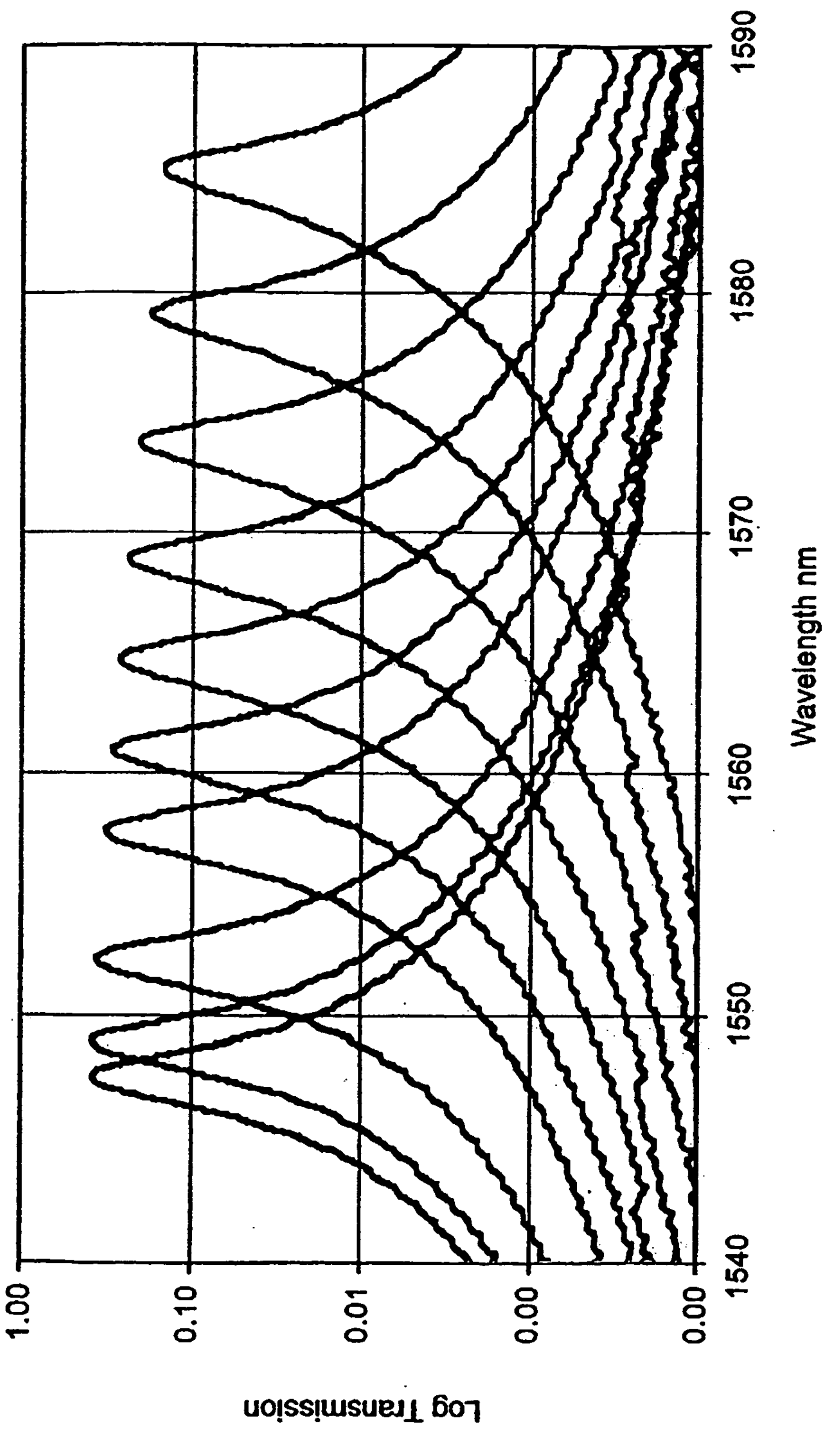
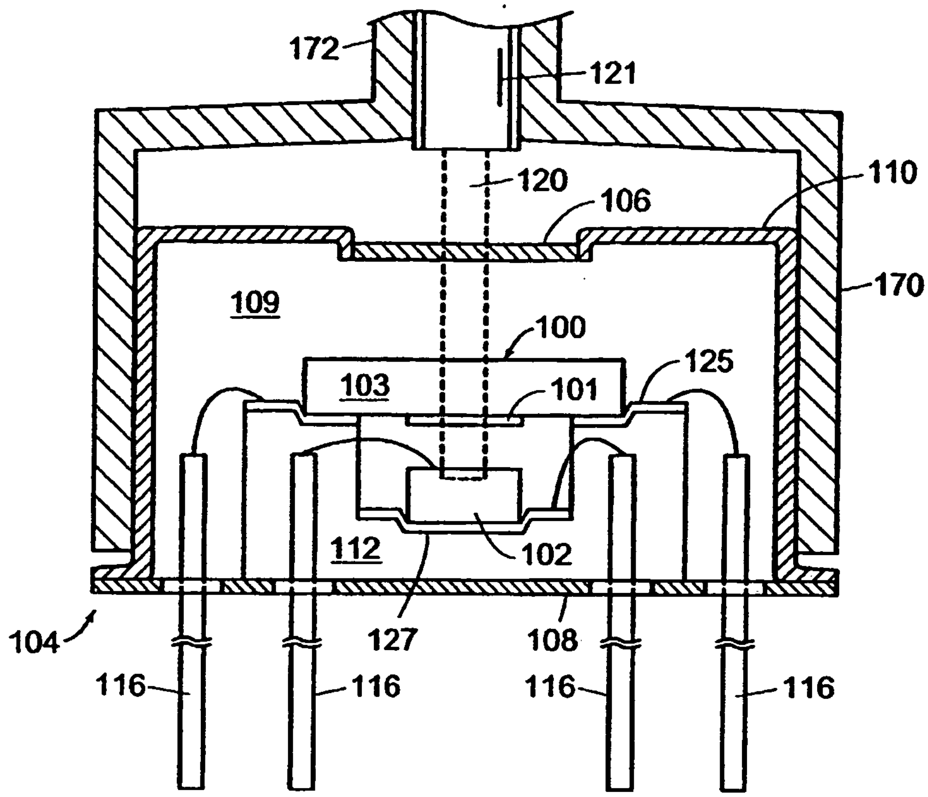

Log Transmission
1.00
0.10
0.01
0.00
0.00
1540
1550
1560
1570
1580
1590
Wavelength nm

FIG. 4


172
121
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112
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104
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116
116

FIG. 5A

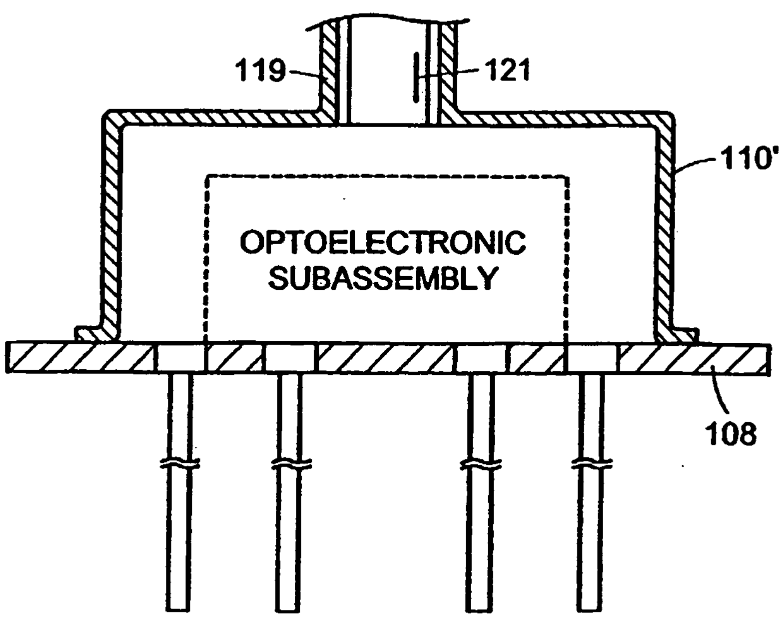

119
121
110'
OPTOELECTRONIC
SUBASSEMBLY
108

FIG. 5B

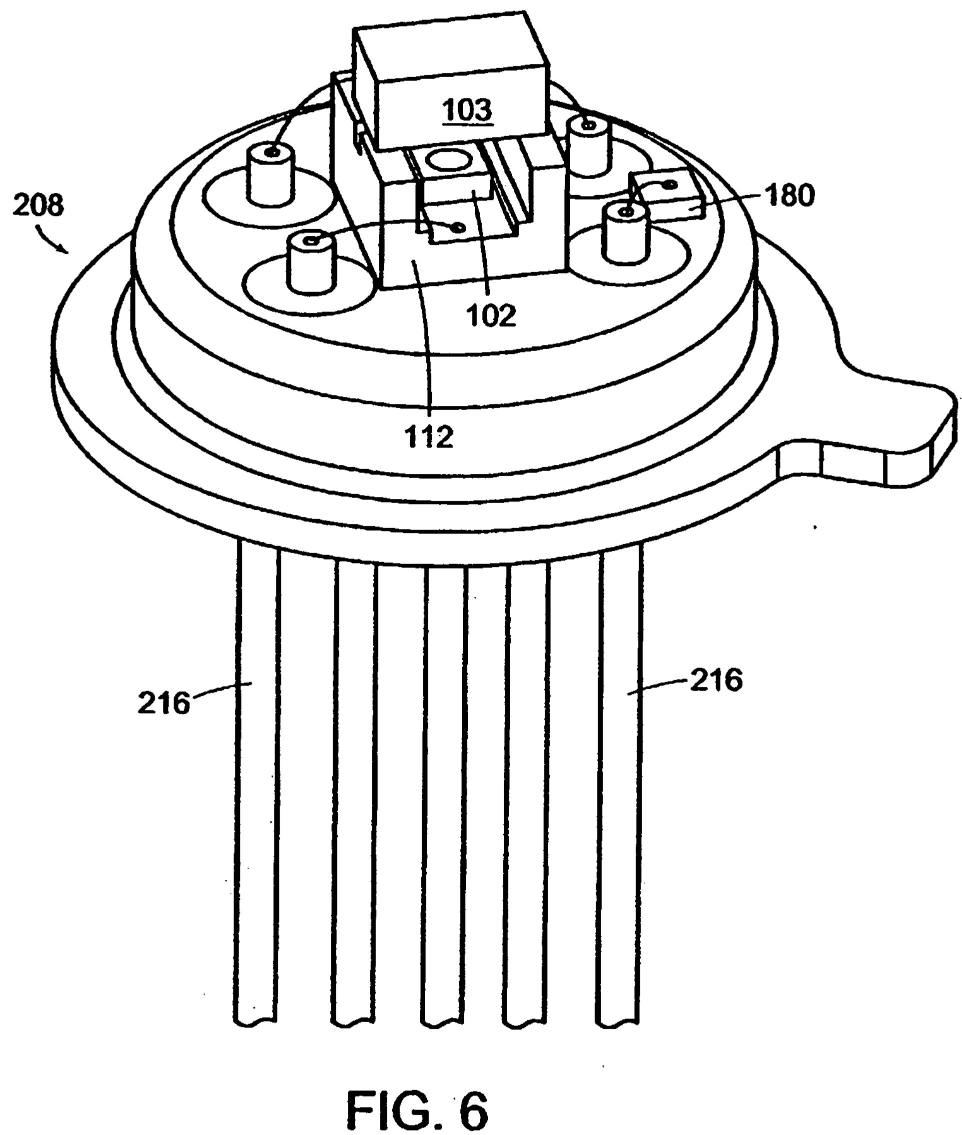



FIG. 6

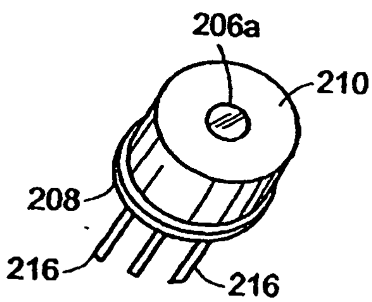



FIG. 7A

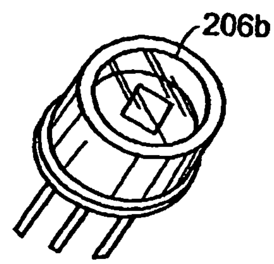



FIG. 7B

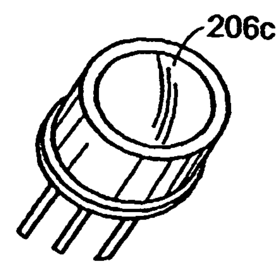



FIG. 7C

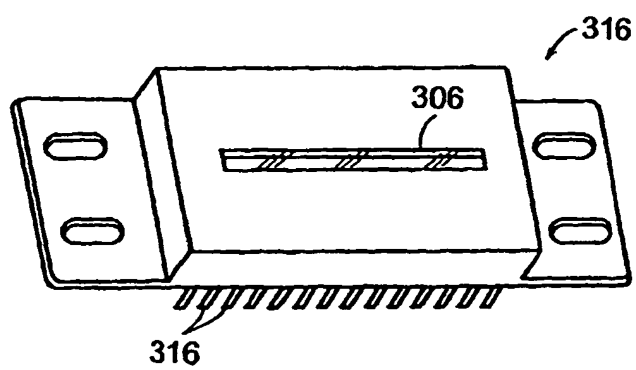
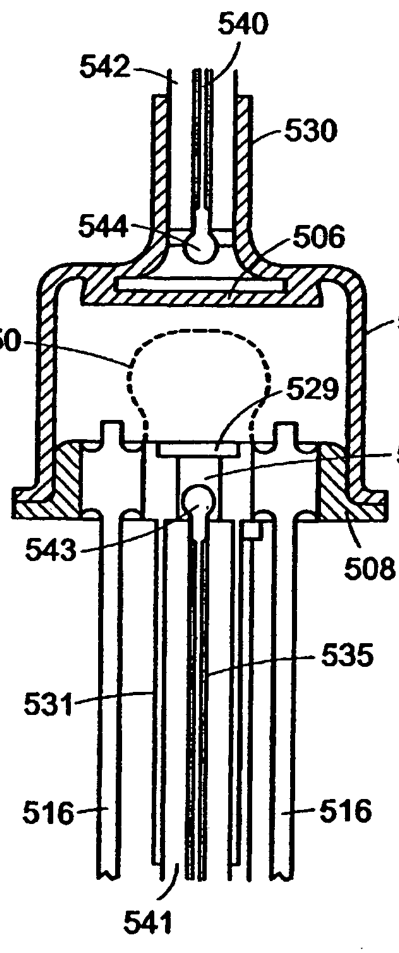



FIG. 7D


540
542
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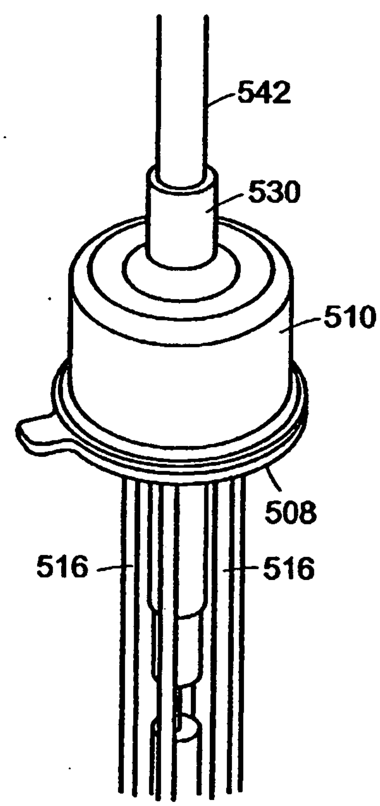
508
535
531
516
516
541

FIG. 8A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516
516

FIG. 8B

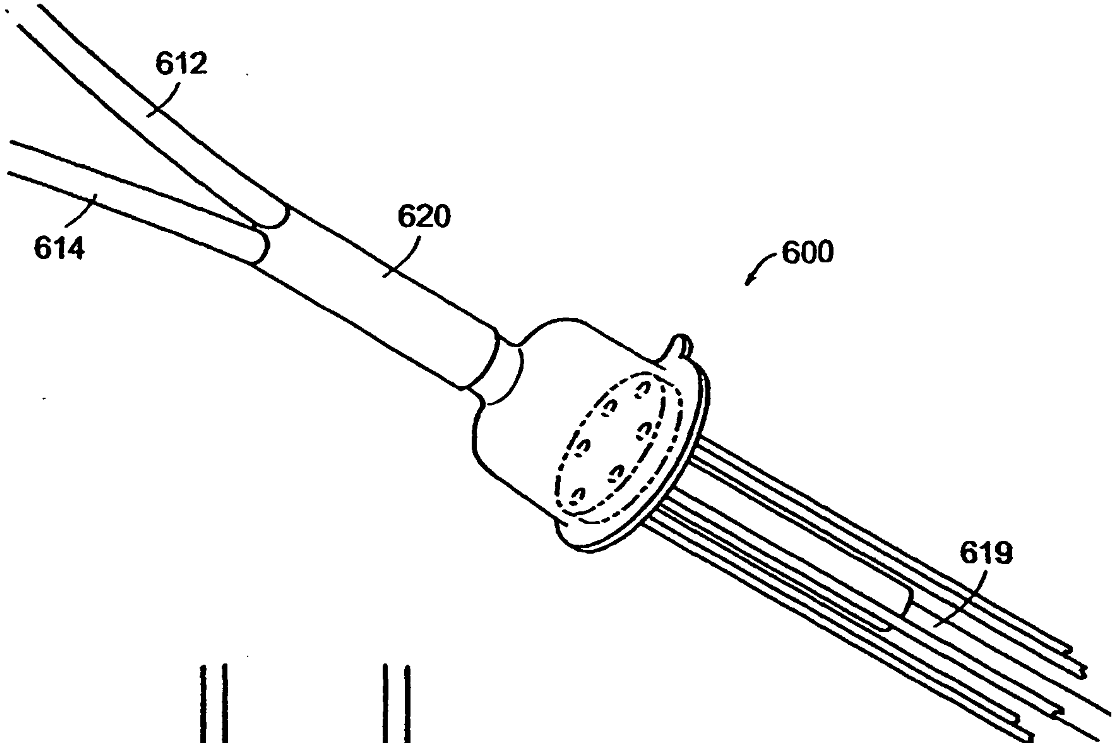


FIG. 9A

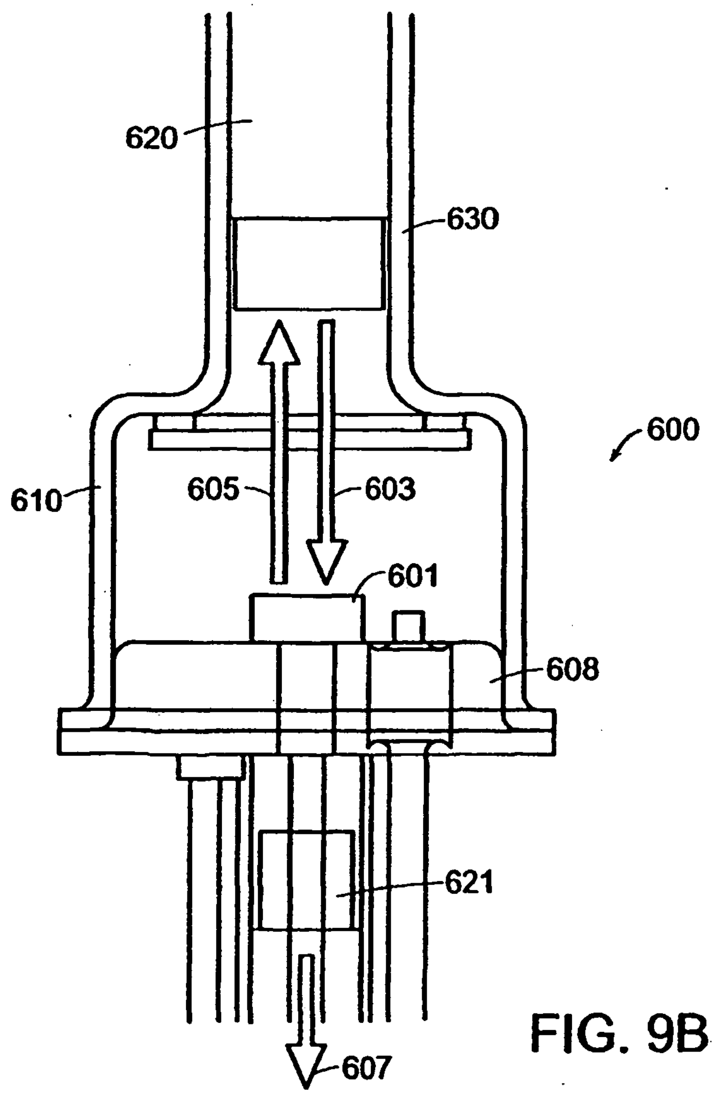


FIG. 9B

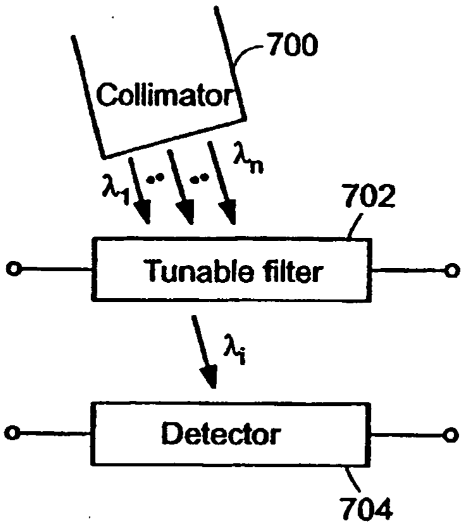


FIG. 10A

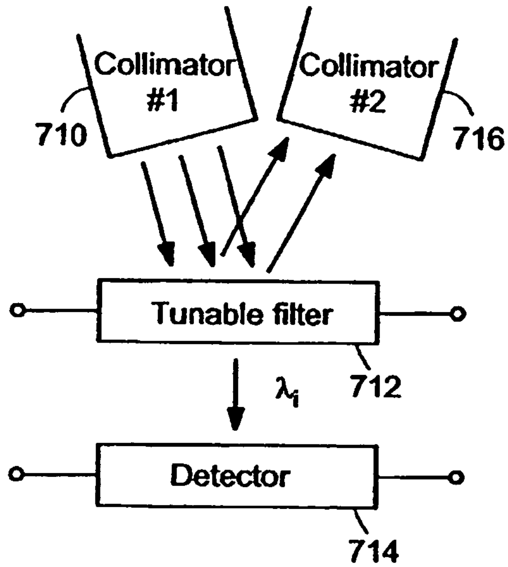


FIG. 10B

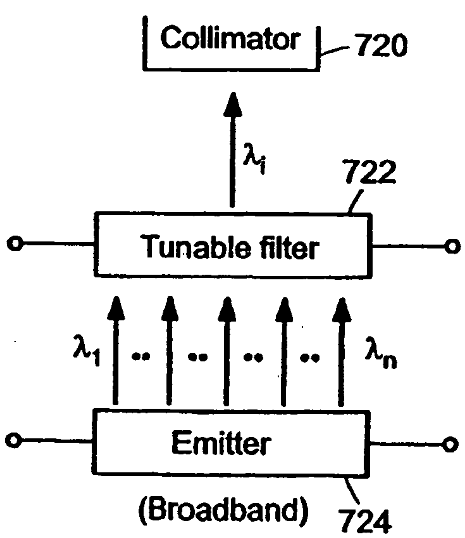


FIG. 10C

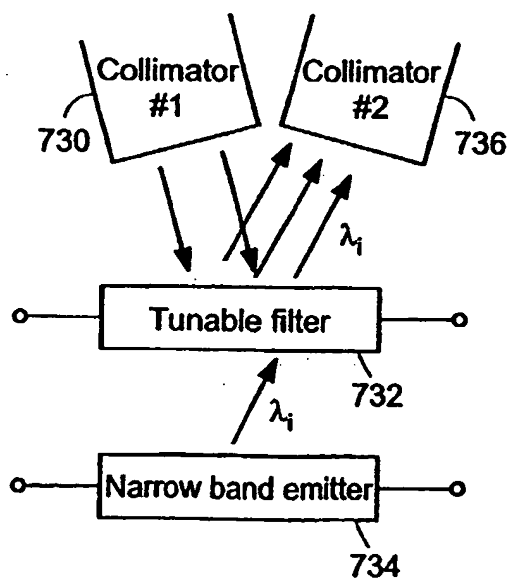


FIG. 10D

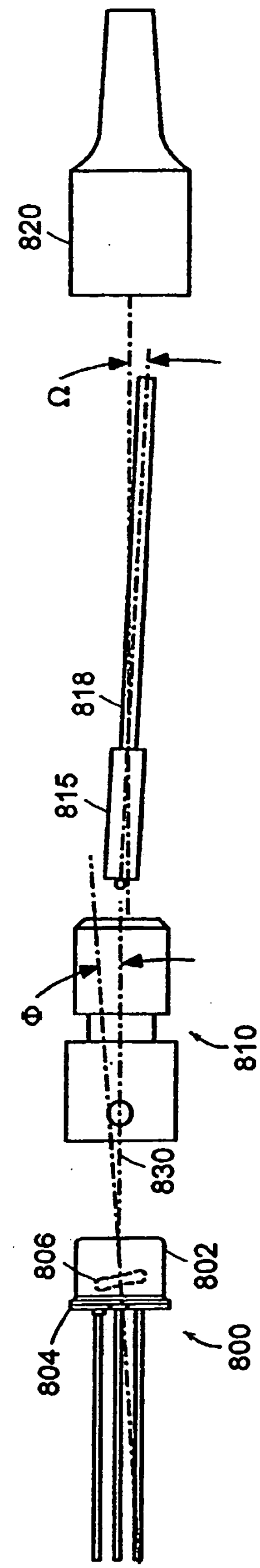


FIG. 11

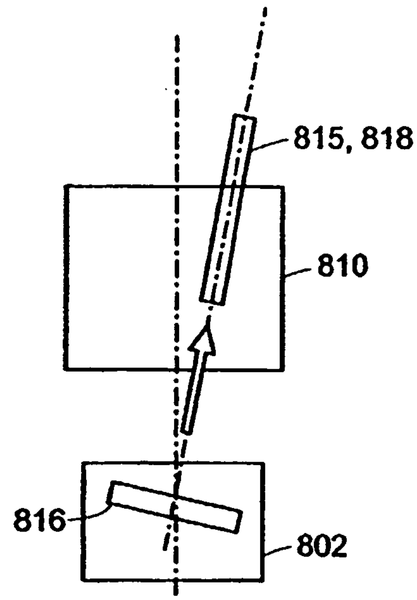


FIG. 12A

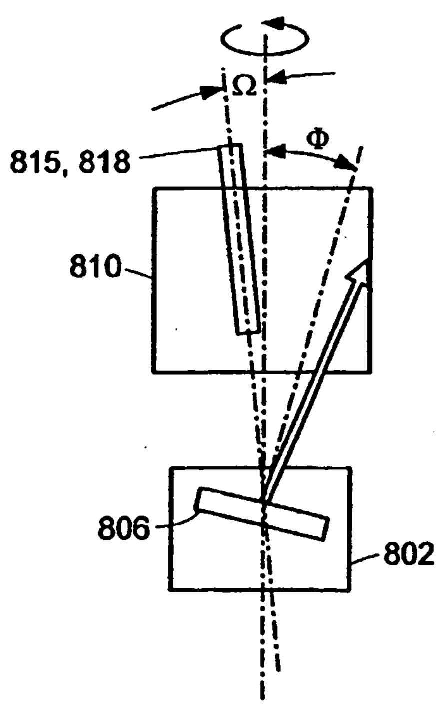


FIG. 12B

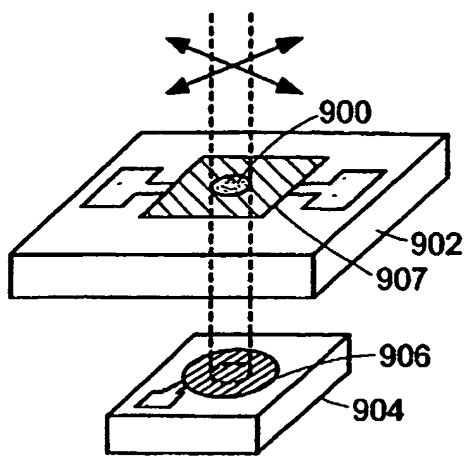


FIG. 13A

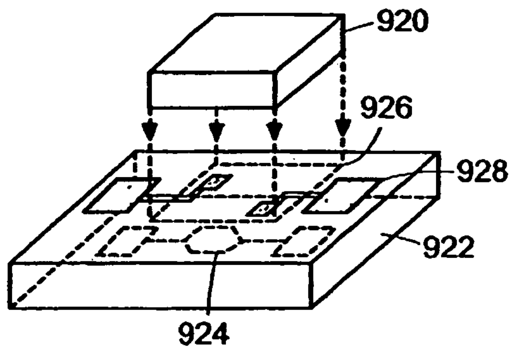


FIG. 13B

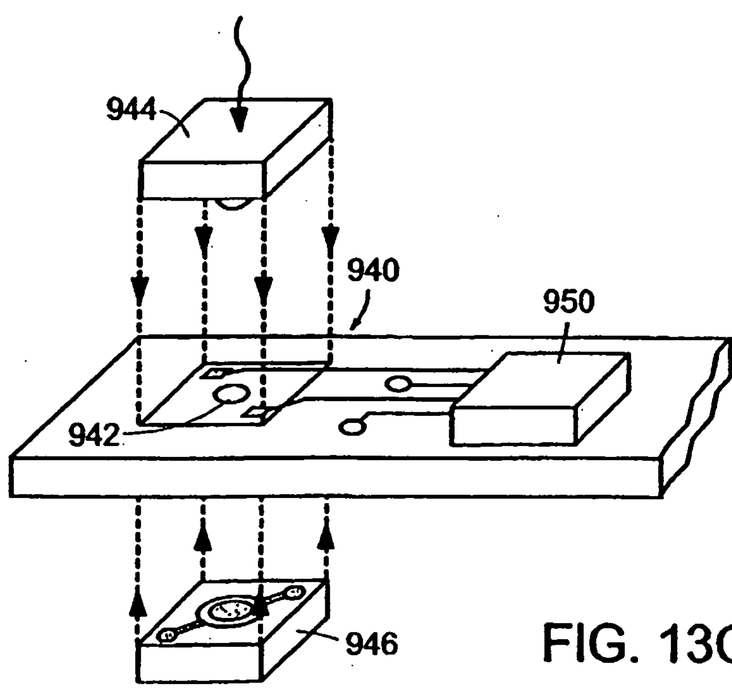


FIG. 13C

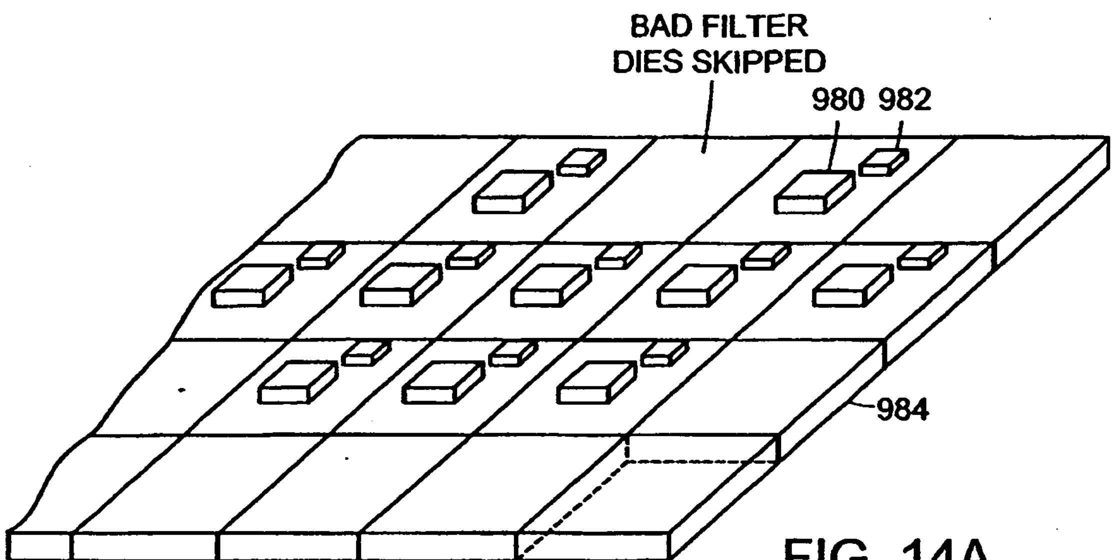


FIG. 14A

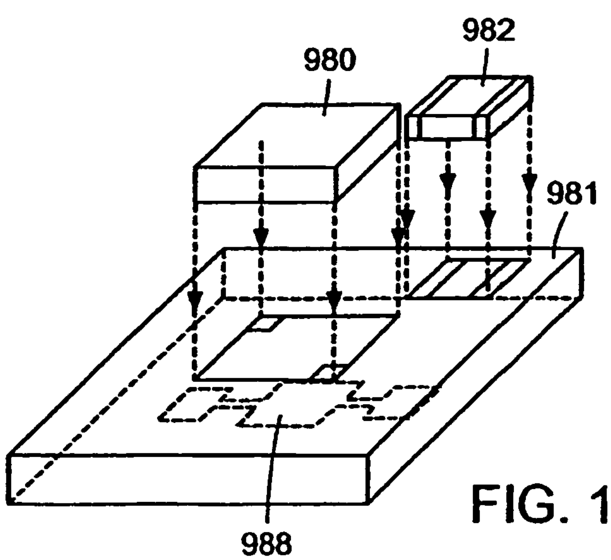


FIG. 14B

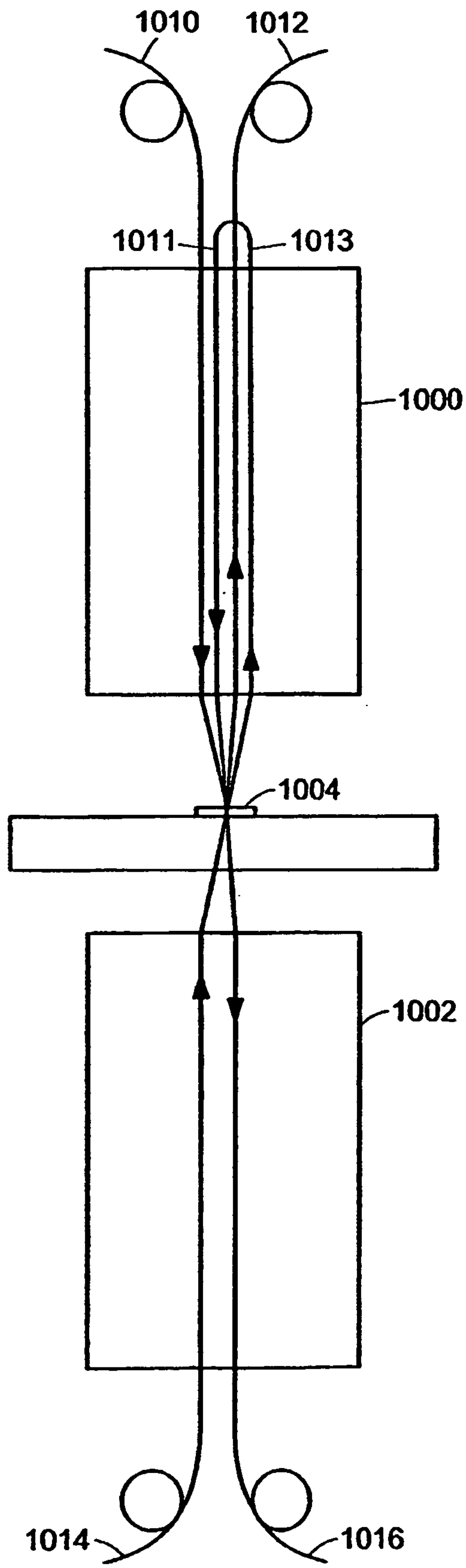


FIG. 15

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/38074

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B6/42

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | WO 01 16637 A (EPITAXX INC)<br>8 March 2001 (2001-03-08)<br>page 6, line 4 - line 23; figure 1<br>page 9, line 1 - line 13; figure 3<br>--- | 1-19 |
| Y | DE 44 24 717 A (DAIMLER BENZ AEROSPACE AG)<br>18 January 1996 (1996-01-18)<br>the whole document<br>--- | 1-19 |
| Y | EP 0 901 170 A (SUMITOMO ELECTRIC INDUSTRIES) 10 March 1999 (1999-03-10)<br>paragraph '0085! - paragraph '0088!; figure 16<br>paragraph '0064! - paragraph '0070!; figure 11<br>---<br>-/-- | 1-19 |

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 17 March 2003 | 25/03/2003 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Frank, W |

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/38074

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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| Y | US 5 408 319 A (HALBOUT JEAN-MARC ET AL)<br>18 April 1995 (1995-04-18)<br>the whole document<br>----- | 1-19 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/38074

| Patent document cited in search report | | Publication date | Patent family member(s) | | Publication date |
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| | | | US | 6043550 A | 28-03-2000 |
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| | | | EP | 1188084 A1 | 20-03-2002 |
| | | | WO | 0023838 A1 | 27-04-2000 |
| | | | US | 2003007747 A1 | 09-01-2003 |
| | | | US | 6390689 B1 | 21-05-2002 |
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